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VERY HIGH MULTIPLICITY PHYSICS

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Status of Very High Multiplicity Physics

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Dear colleagues!

It's my pleasure to make this presentation on the Workshop, dedicated to the memory of **Leonid Slepchenko**, - our friend and talented physicist, who passed away exactly one year ago.

First of all I'd like to note:

Of course, everybody understands that "the main road" of particle physics development is connected with the "Standard Model" and with the questions beyond it (may be SUSY, I mean). But I'd like to stress that there are other roads which lead to understanding of other aspects of Nature. The Very High Multiplicity physics is one of them.

The topic of my talk is to describe a general situation around the phenomena, now known as the Very High Multiplicity physics. I'd like to discuss briefly both, the theoretical status and the experimental perspectives.

The talk is based namely on the papers shown in the **References**:

[1] J.Manjavidze & A.Sissakian, JINR Pap. Comm., P2-88-724, 1988; 5/31 (1988) 5; 2/281 (1988) 13

[2] J.Manjavidze & A.Sissakian, Phys. Rep., April (2001)

[3] J.Manjavidze & A.Sissakian, J. Math. Phys., 41 (2000) 5710, 42 (2001) 641, to be published (2001)

[4] J.Manjavidze & A.Sissakian, Th. Math. Phys., 123 (2000) 776, to be published (2002)

events was formulated in the papers published in **JINR Rapid Communication**.

The **Phys. Rep.** contains mainly the qualitative features of the VHM physics. But it contains also a large number of Appendices with mathematics.

The three paper of **Journal of Mathematical Physics** and two paper in the **Theoretical and Mathematical Physics**, last one is the review paper over 60 pages, contain the formalism of future generator of the very high multiplicity events. I will return to this question at the very end of my talk.

1 Introduction

The characteristic features of VHM events

Generally, I'd like to consider the processes with multiplicity

$$n >> \bar{n}(s),$$

where $\bar{n}(s)$ is the mean multiplicity, see Fig.1.

The VHM domain can be specified more considering the details of production processes. I'll discuss this question later.

One may introduce also the inelasticity coefficient

$$\kappa = \frac{E - \epsilon_{\max}}{E},$$

where E - total energy in the given frame, $\epsilon_{\max}$ - energy of the fastest particle in the given frame. Then, VHM events mean

$$1 - \kappa << 1.$$

So, the produced particles momentum is comparatively small.

At the same time, we would like to exclude the influence of the phase space boundaries. For this reason, we would like to assume that the multiplicity can not be too large:

$$n << n_{\max} = \frac{E}{m}, \quad m \approx 0.2 \text{ GeV}.$$

¿From the experimental point of view VHM includes the extremely rear processes, see Fig.2. At all evidence, the cross sections fall down faster then any power of $1/n$ (one over n):

$$\sigma_n < O(1/n).$$

This estimation is natural in the ordinary S-matrix formalism frame, assuming that the radii of interactions is finite I mean. For this reason the B rang of multiplicity on the Fig.2 is not attainable.

But the cross section may fall down as the any inverse power of multiplicity: $\sigma_n \sim 1/n$, or even temporary rise with multiplicity in the VHM domain. This regime is out of the traditional S-matrix formalism, where it is assumed that the produced particles are free from arbitrary influences. I hope that this possibility will be discussed in the talk of **professor Vladimir Nikitin.**

2 Phenomenology

One may expect that various mechanisms of particle production would realized with rising multiplicity. This is natural since the kinematical conditions would changed with multiplicity. I'd like to mention here that this bright idea was offered firstly in our papers prepared together with **Leonid Slepchenko**, about 30 years ago. See:

[5] A.N.Sissakian and L.A.Slepchenko, Preprint JINR, P2-10651, 1977;
A.N.Sissakian and L.A.Slepchenko, Fizika, 10 (1978) 21;
S. Ch. Mavrodiev, V. K. Mitryushkin, A. N. Sissakian and H. T. Torosyan, Sov. Yad. Phys., 30 (1979) 245

⋆ It can be shown that only three classes of asymptotics exist:
— The cross section falls down faster then any power of exponent of $(-n)$:

$$\mathbf{I}: \quad \sigma_n < O(e^{-n}): \ \textbf{multiperipheral interactions}$$

— The cross section falls down as the exponent:

$$\text{II}: \quad \sigma_n = O(e^{-n}) : \ \textbf{hard processes}$$

— The cross section falls down slowly then any power of exponent of $-n$:

$$\text{III}: \quad \sigma_n > O(e^{-n}) : \ \textbf{vacuum instability}$$

⋆ Having in mind the idea that the cross section is extremely small in the VHM domain, it is useful to present this classification in the "rough" terms. If

$$\mu = <\varepsilon> \frac{1}{n} \ln \frac{\sigma_{tot}}{\sigma_n}$$

then, in the VHM region, see Fig.3,

$$\text{I}: \ \frac{\partial}{\partial n}\mu(n) > 0, \quad \text{II}: \ \frac{\partial}{\partial n}\mu(n) = 0, \quad \text{III}: \ \frac{\partial}{\partial n}\mu(n) < 0.$$

If ε is the mean energy of produced particles, then the "chemical potential" μ is the work needed for one particle production.

⋆ **The VHM events can distinguish this three possibility.** Thus, we expect transition from regime **I** to **II** in the VHM domain.

So, **I** means that the difficulty of particle production rise with rising multiplicity

II means that there is a "macho" parent and it is easily, without problems produce particles

III is realized if the ground state is unstable against particle production.

It should be stressed that there is not any other possibility in the ordinary S-matrix formalism, or quantum field theory.

3 Thermodynamics

It should be mentioned that the multiple production amplitude is a function of $(3n-4)$ variables. On other hand, we know that the "statistical system" can be described by a few variables only.

⋆ **So, the thermodynamical method would be necessary to describe the system completely.**

Considering the multiple production process as the example of ordinary cooling, number of produced particles n measures the thermalization rate. I mean that the produced particles are the "evaporated" ones (**evaporate -**) and the statistical interpretation of the VHM events may be available for this reason.

Therefore,

— The VHM final state should be close to the "equilibrium", i.e. be "calm" and "cold", I mean.

⋆ **Notice that just this conditions are necessary for observation of the collective phenomena**: phase transition in the colored plasma, for instance.

Thus, it is extremely important to know where the thermodynamical description is valid.

The corresponding necessary and sufficient condition looks as follows: $|K_l(E,n)|^{2/l} << K_2(E,n)$, where K_l are the ordinary l-particle energy correlators. For instance, $K_2(n,E) =$ ..., and $K_3(n,E) =$ ... etc. The l-particle mean energy is defined by well known equality: $< \varepsilon^l; n, E >=$ ..., where

$$d^{3l}\sigma_n(E)/d^3q_1 d^3q_2 \cdots d^3q_l$$

is the corresponding differential cross section.

I'd like to note that derived condition of the thermodynamical description validity reminds the "correlations relaxation" principle offered by Nikolai Nikolaevich Bogolyubov for nonequilibrium thermodynamics.

The PITHYA prediction for ratio K_3 to K_2 is shown on Fig.4.

Notice that it did not predicts even tendency to equilibrium. But, on other hand, we have a formal prove that the system should come to equilibrium in the deep asymptotics over multiplicity. Here I mean that the ratio K_3 to K_2 should tend to zero with multiplicity. This is a formal, mathematical, theorem.

Therefore, having in mind that used generator of events based on the hadron peripheral interactions phenomenology, we can conclude that investigation of the ratio K_3 to K_2 in the VHM domain will allow to define the range of applicability of the peripheral picture of hadron interactions.

I'd like to note here importance of investigation of this question in the heavy ions collisions. Indeed, there is the idea that having a large number of hadrons in the initial state, one may assume that the thermalization effect will be attained. So, measurement of the ratio K_3 to K_2 should help to check this basic idea. It is crucial for searching of the colored plasma. We start discussion of this question with the STAR (RHIC) community.

4 Model predictions

The attempts of naive transition of the existing models prediction into the VHM region was performed. Result looks as follows.

Multiperipheral kinematics, see Fig.5, $q_{1||} ... >> q_{n||}$. It is known that

— Multi-Pomeron contribution work up to $n \sim \bar{n}(s)^2$

— Multiperipheral kinematics predict, see Fig.6, $\frac{\partial}{\partial n}\mu(n) > 0$. Out of this range there is not predictions: model did not "work". But in the range of its applicability,

— No tendency to "equilibrium" is valid

Dual-Resonance model.

— Exponential grow of the resonance mass spectrum predicts KNO scaling law

$$\mu(n) \propto \text{const.} \quad \text{for} \quad n < \bar{n}(s)^2$$

$$\frac{\partial}{\partial n}\mu(n) > 0 \quad \text{for} \quad n > \bar{n}(s)^2;$$

This is typical change of interaction dynamics. The absence of tendency to thermalization is seen once again. This is natural since the dual-resonance model predicts the same momentum spectra as the multiperipheral model.

DIS kinematics, see Fig.7,

$$q_{1\perp} >> q_{2\perp} >> ... >> q_{n\perp}, \quad q_{i\|} \approx const., \quad i = 1, 2, ..., n.$$

— DIS kinematics predict, see Fig.8,

$$\mu(n) \to \text{const. for } n >> \bar{n}(s).$$

This proves the offered above idea that the VHM processes should be hard.

So, one can hope to investigate the VHM domain using perturbative QCD. But — **the effect of softening of the spectra in the VHM domain makes problematic the Leading Logarithm ideology, ordinary used, for instance, for verification of the multiperipheral picture. This is the general (model-free) conclusion.** It means practically that the perturbative QCD calculations in the VHM region are out the human opportunity (human recourses, I mean).

There will be the introductory talk into the Leading Logarithm Approximation of **prof. Lev Lipatov. Edward Kuraev** will discuss the double logarithm approximation. May be they will change our pessimistic position.

Anyway, the experimental information in the VHM region seems from this point of view important.

5 Experiment

⋆ **Rough description**

We should take into account that the VHM cross sections are extremely small. For this reason, the "rough measurements" only can be performed. So:

(i) The multiplicity is the hardly measurable parameter.
For this reason we trying to formulate the VHM theory without notion of multiplicity n. For instance, to have the VHM final state one can restrict from below the inelasticity coefficient.

(ii) It is practically impossible to restore the VHM kinematics completely.
It was offered for this reason to consider the correlation among the "groups" of particles. This possibility will be discussed on this Workshop by **Yuri Kulchitski.**

⋆ **Generator of events**

Being without even a model of VHM processes,

— The Generator of Events (GE) should be constructed. This is our main problem. The status of this problem will be discussed in the talks of **Nikolai Amelin, Nodar Shubitidze and Joseph Manjavidze.**

So, we have the new perturbation QCD theory. It includes old perturbative QCD as an approximation. It is free from divergences. I'd like to underline here that this is a first example of such divergences-free non-trivial quantum field theory in the 4-dimensional space-time. By definition it is applicable at all distances and includes, using old terminology, non-perturbative effects.

⋆ **Toward the experimental program**

I'd like to extract following qualitative problems.

— The thermalization problem, i.e. the question: would the *experimentally observed* VHM event "equilibrium". The experimental efforts both in **hadron** and in **nuclei** inelastic collisions are important.

— Quantitative definition of the range of validity of the LLA in the VHM domain. As I know, the status of this program on the ATLAS experiment will be discussed by **Stefan Taprrogge.**

6 Conclusion

The VHM problem highlights the mostly painful questions of the hadron physics.

(A) Phase transition in the colored state, I mean

The VHM gives a good chance for it since the state is "calm" and "cold". Last one means that the interaction energy is larger then the kinetic one if we have the VHM final state.

I have mentioned above that the ration (σ_n/σ_{tot}) can be interpreted in the VHM domain as the partition function. Then, its change with multiplicity, or with the inelasticity coefficient, can be considered as the "heat capacity". Thus following idea becomes evident: comparing the electro-week production channel with hadron production channel, one can investigate the coloured charge condensation into the hadrons phenomena. If in the VHM domain the corresponding heat capacities did not coincide then it would be a **direct** prove of the phase transition (condensation) existence.

(B) The "pre-confinement" VHM state presents the **equilibrium** colour plasma. This means that it can be characterized by the few global parameters. In this sense it will be the "state".

This conclusion is extremely important for coloured plasma and is extremely important for ion collision experiments. For this purpose the ratio K_3 to K_2 should be measured.

(C) The ratio $R = <p_{\parallel}>/<p_{\perp}> = \pi/4$ for isotropic case, when the end of produced particle momenta locate on the sphere.

In the "multiperipheral picture" domain $R > \pi/4$ (R is larger than π over 4). If our prediction is rightful, then in the VHM domain one can expect that R is less than π over 4.

(D) The process of VHM production is "fast". For this reason **the isotop spin orientation may be frozen randomly**. Experimentally it looks like large fluctuations of the charge: if $C = n_c/n_0$ is the ratio of charged to neutral particle number then the "anomalous" (non-Gaussian) distribution over C is expected.

So, exist prediction that the charge fluctuation is proportional to the inverse power of multiplicity. As the indication of large charge fluctuation the cosmic ray CENTAUR event is considered.

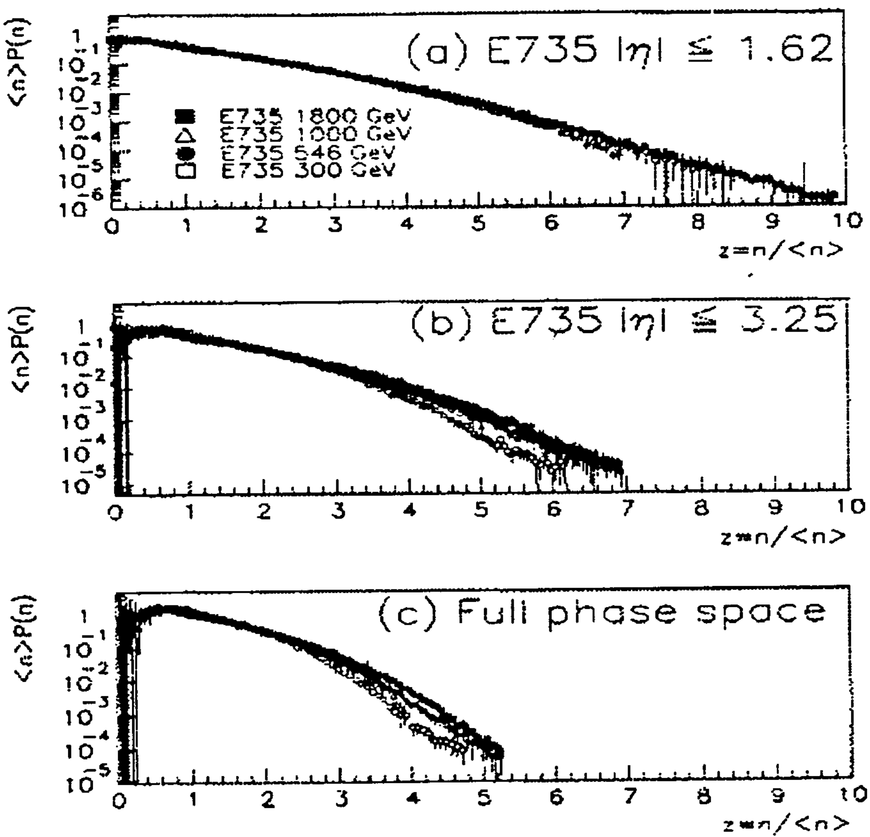

Figure 1: Multiplicity distribution

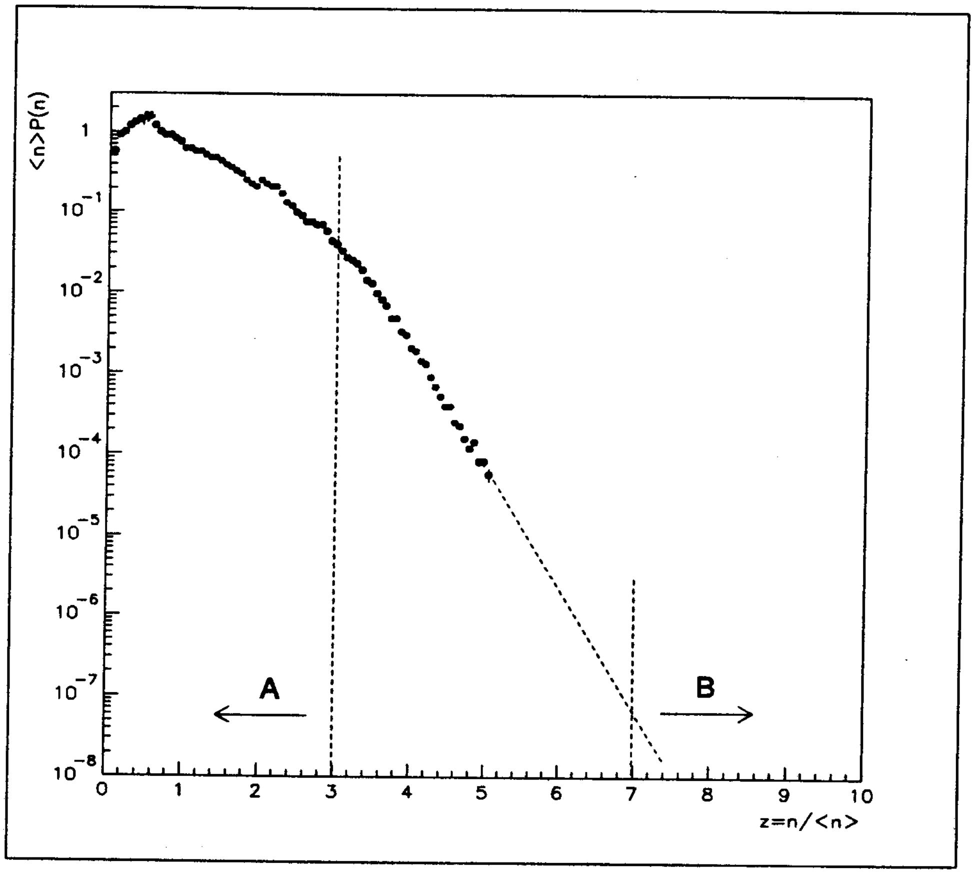

Figure 2: Definition of the VHM region of multiplicity

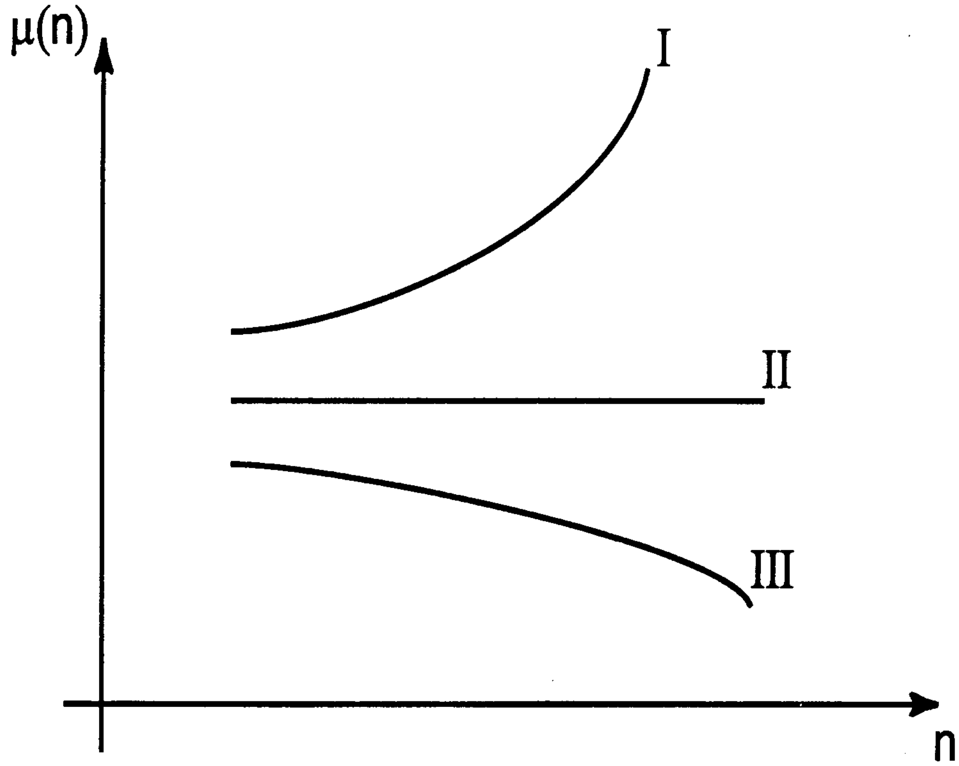

Figure 3: "Chemical potential"

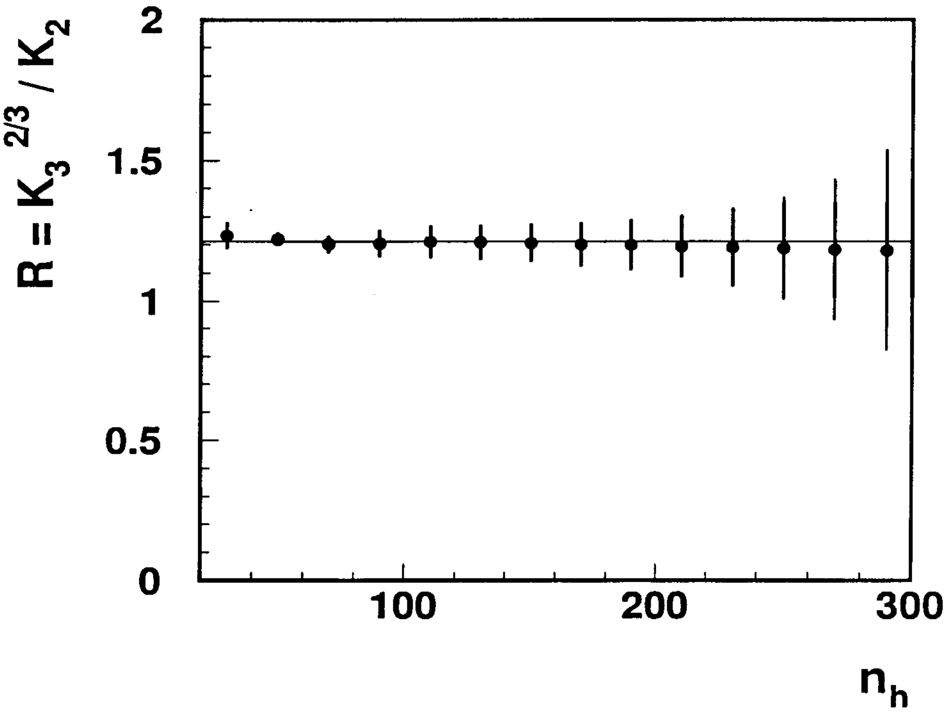

Figure 4: $K_3 - K_2$ ratio

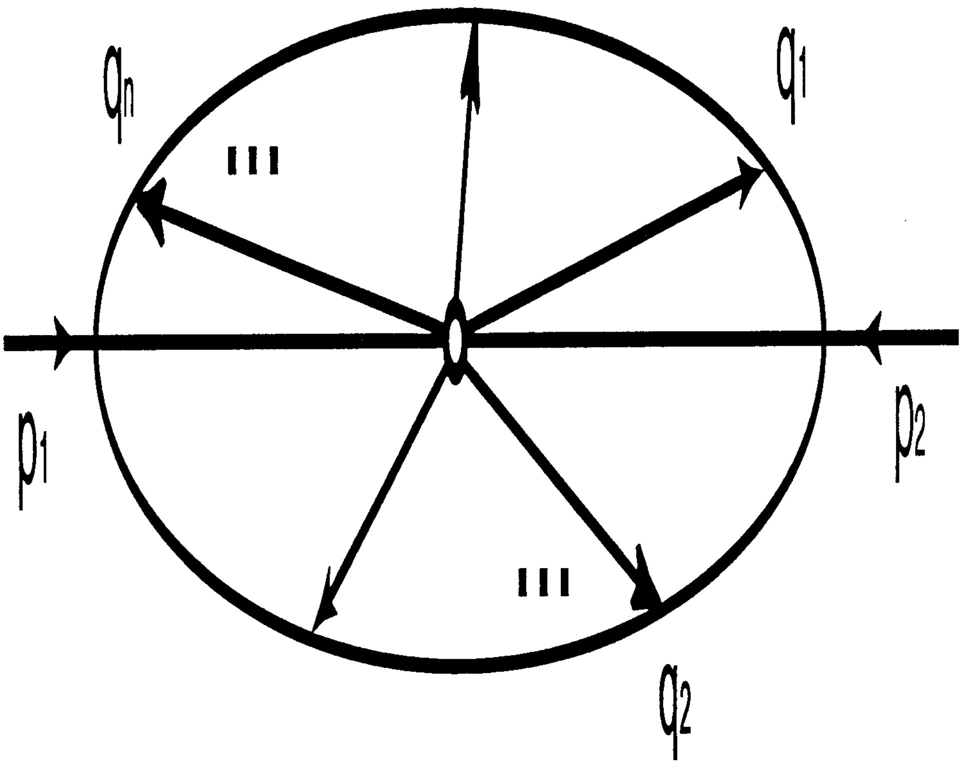

Figure 5: Multiperipheral kinematics

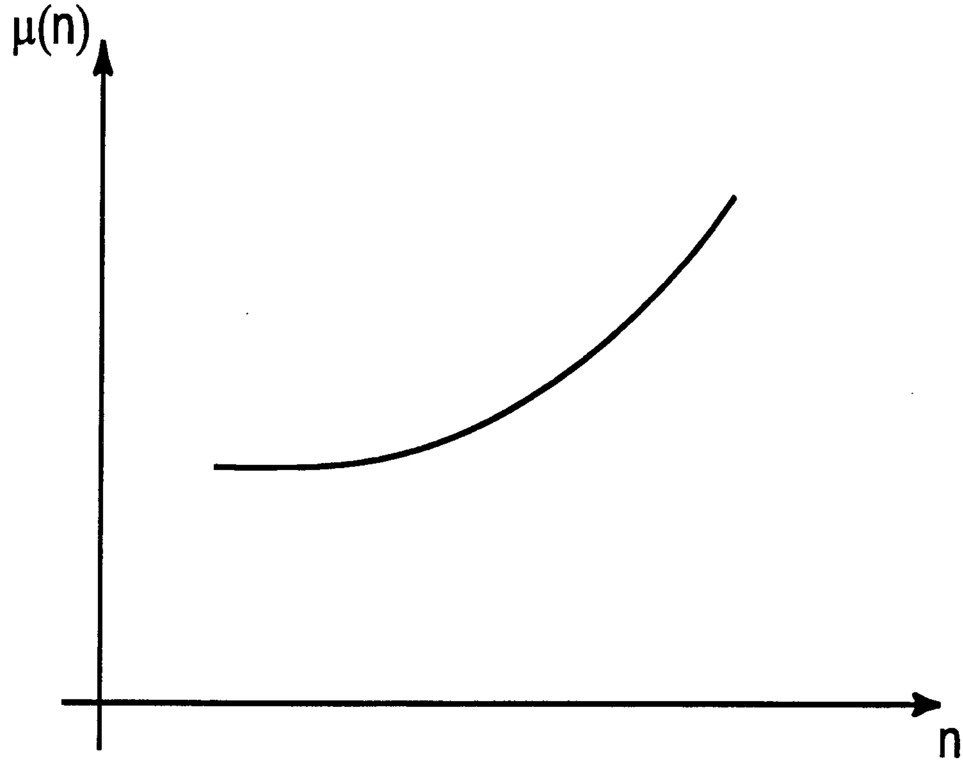

Figure 6: Multiperipheral model

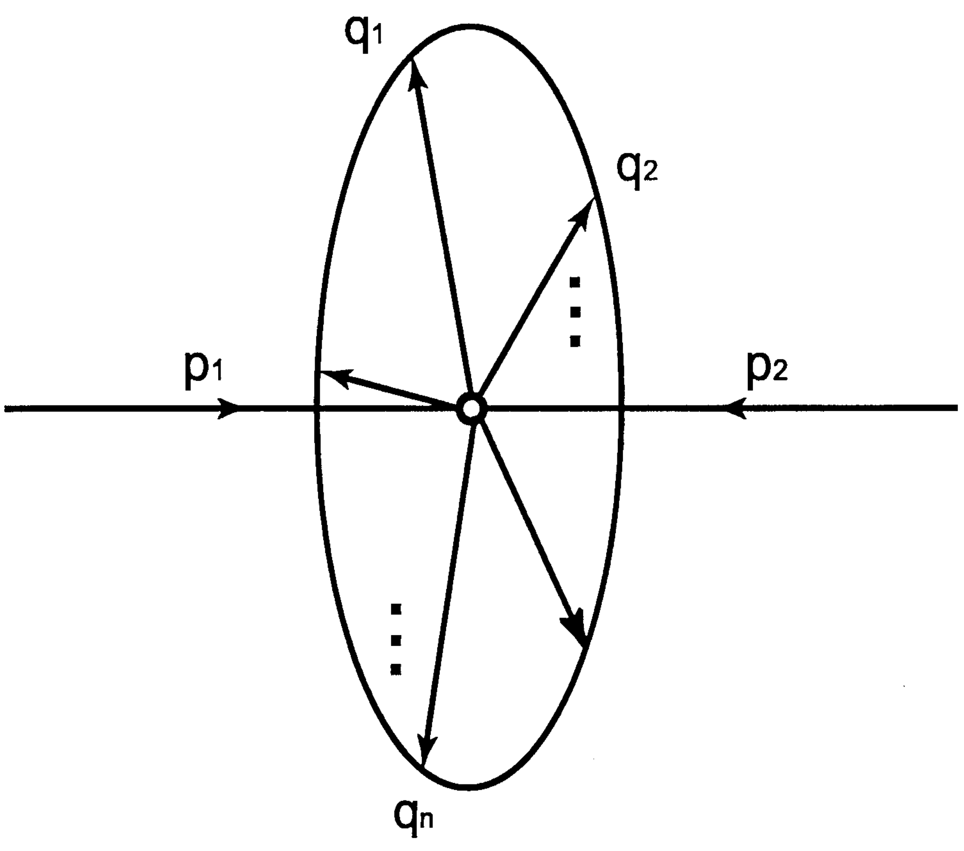

Figure 7: DIS kinematics

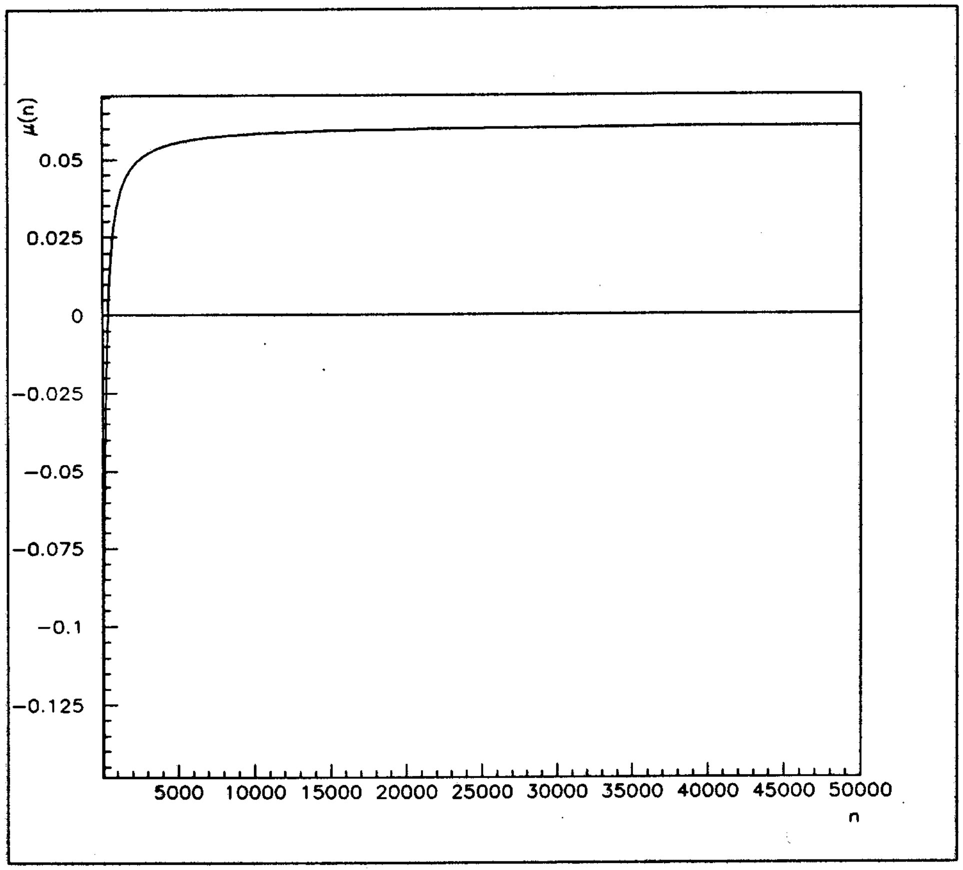

Figure 8: QCD jets production